Integration of an Individual-Based Fish Bioenergetics Model into a Spatially Explicit Water Quality Model: Chesapeake Bay

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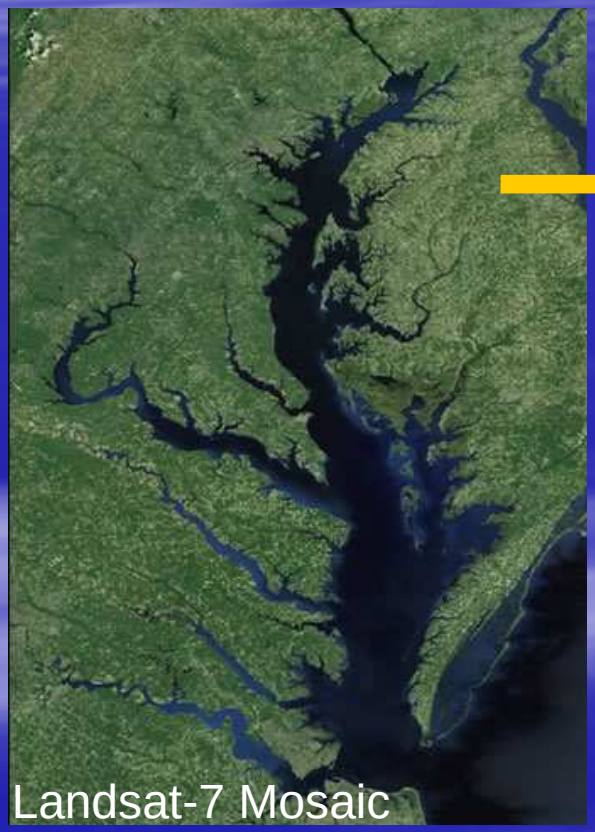
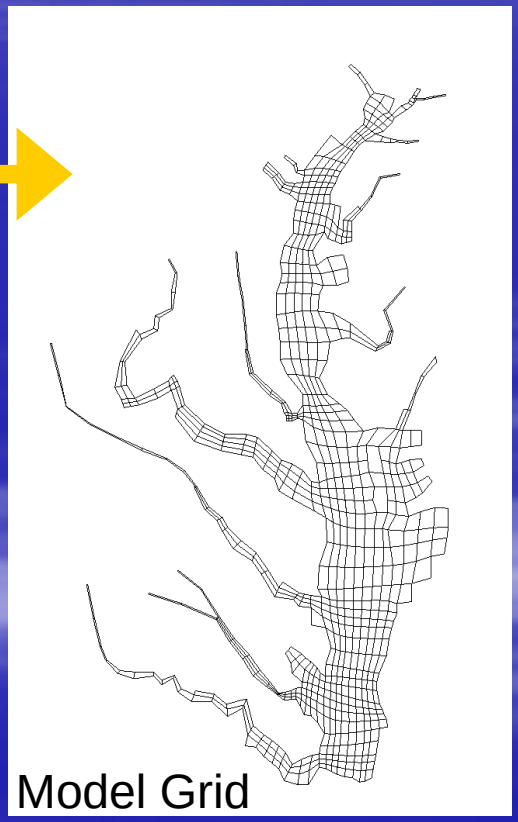
Ecosystem Health: Management & Modeling

- "Top down" strategy: higher trophic levels (e.g., oysters, menhaden) can effect as well as be effected by H_2O quality
- Water quality model contains nutrients, algae, zooplankton
- Existing phytoplankton consumption models for menhaden spatially/temporally averaged
- Current effort: imbed individual-based fish model into water quality model

Chesapeake Bay
CE-QUAL-ICM Eutrophication Model





20 miles

Chesapeake Bay:

- Largest estuary in US
- >3600 species aquatic animals, 2700 plant species
- Historic battle with eutrophication

CE-QUAL-ICM:

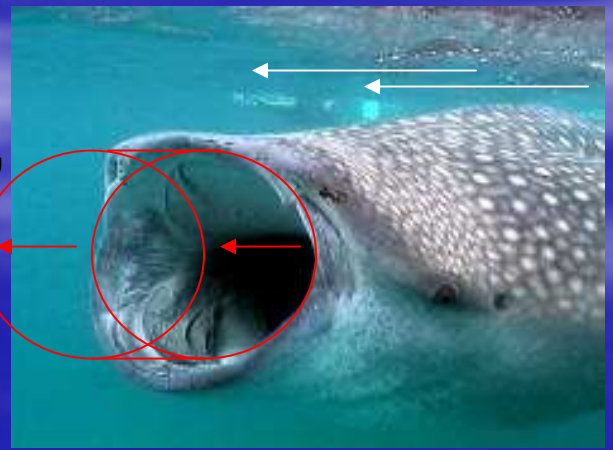
- Spatially/temporally explicit
- Temperature, salinity, carbon, nitrogen, phosphorus, algae, zooplankton
- CB: CH3D hydrodynamics

Atlantic Menhaden

- Spawn off Atlantic coast
- Larvae move into estuaries, grow into juveniles
- Juveniles/adults = filter feeders
- Travel in dense schools of 100,000+ members
- Potential for phytoplankton control, nutrient export

Fish Bioenergetics Module

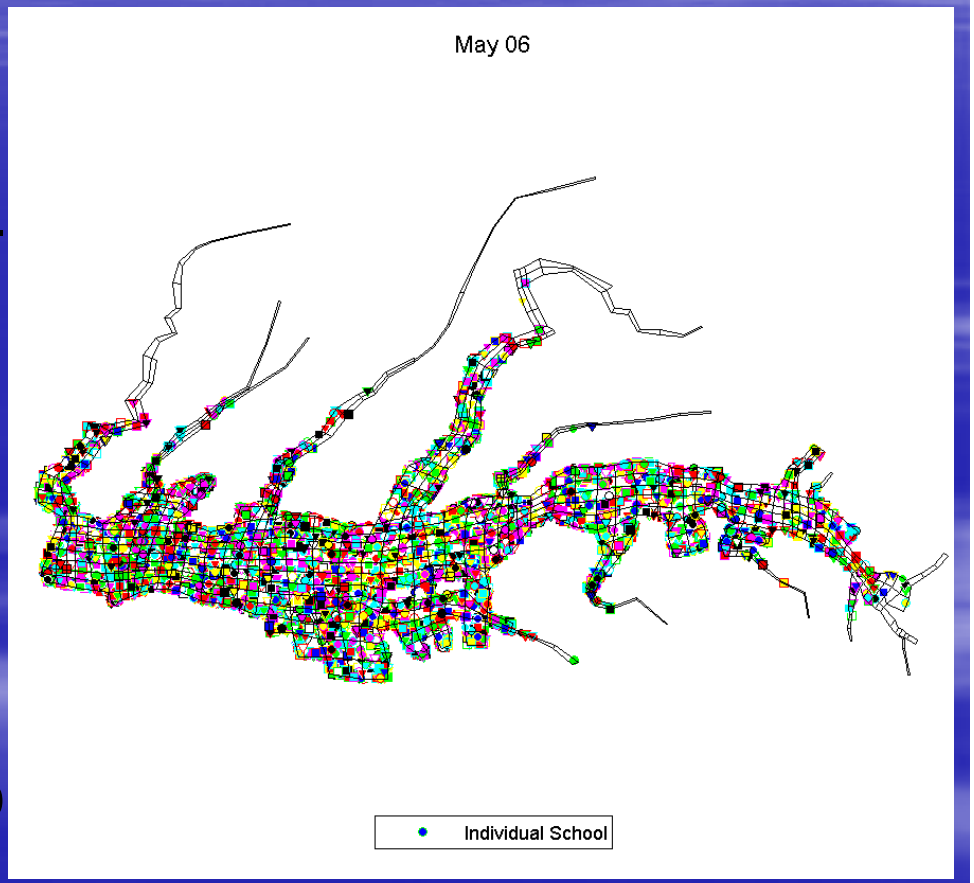
- Wisconsin Fish Model: conservation of energy/mass in fish
- Foraging model for consumption (food in volume swept by fish)
- Calibrated with “feeding fraction” (accounts for non-feeding times)
- Empirical parameters for life processes (respiration, excretion, egestion)
- What’s left goes to growth



Volume = f(speed, mouth area)

Migration Pattern

- 4,000 schools of ~400,000 members
- Delineated by age class (age-0, ages-1&2, age-3)
- Varying entry dates, each school enters at same weight for its age
- Spatially variant biased random walk to replicate migration in/out of the bay (no food response or age specific preferences)



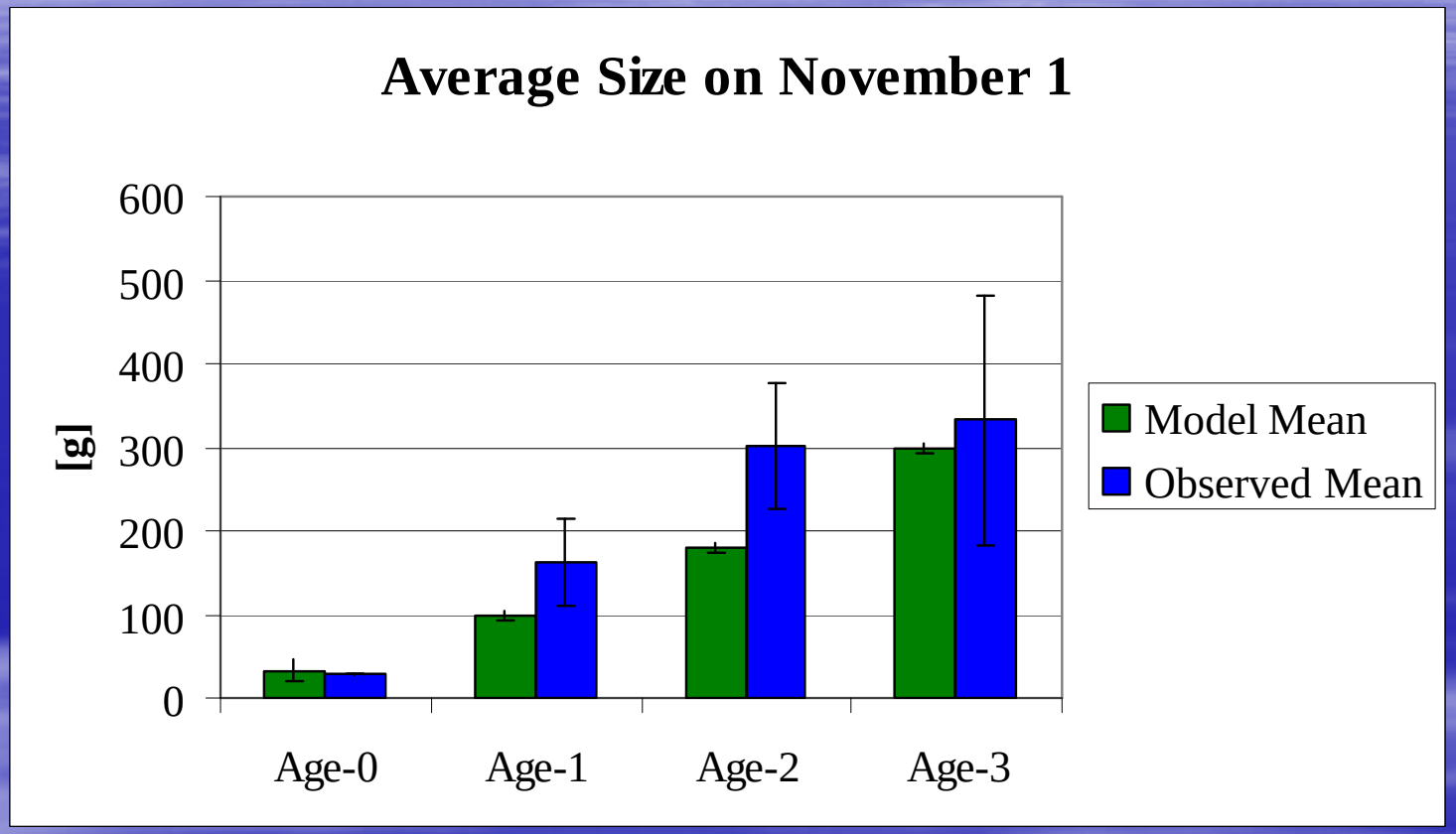
Parametric Study: Initial Population & Fishing Pressure

	Age-0			**Age-1**			**Age-2**			**Age-3**		
Test Case	N_0	AFM	APM	N_0	AFM	APM	N_0	AFM	APM	N_0	AFM	APM
Baseline ($x10^9$)	1.4	0.02	1.23	0.4	0.22	0.72	1.7	0.85	0.60	0.33	1.37	0.55
Low Population	Half initial population, same fishing mortality											
High Population	Double initial population, same fishing mortality											
V. High Population	5x initial population, zero fishing mortality											
High Fish. Mortality	Same initial population, double fishing mortality											
Low Fish. Mortality	Same initial population, half fishing mortality											
Zero Fish Population	Zero population											

N_0 = Population entering the grid, in billions of fish
AFM = Instantaneous annual fishing mortality ($year^{-1}$)
APM = Instantaneous annual natural (predation) mortality ($year^{-1}$)
Baseline population: 10% of estimated average Atlantic menhaden stock, 1985-2005[1]
Baseline mortality: average of fishing mortality-by-age, 1985-2005; stock assessment natural mortality[1]

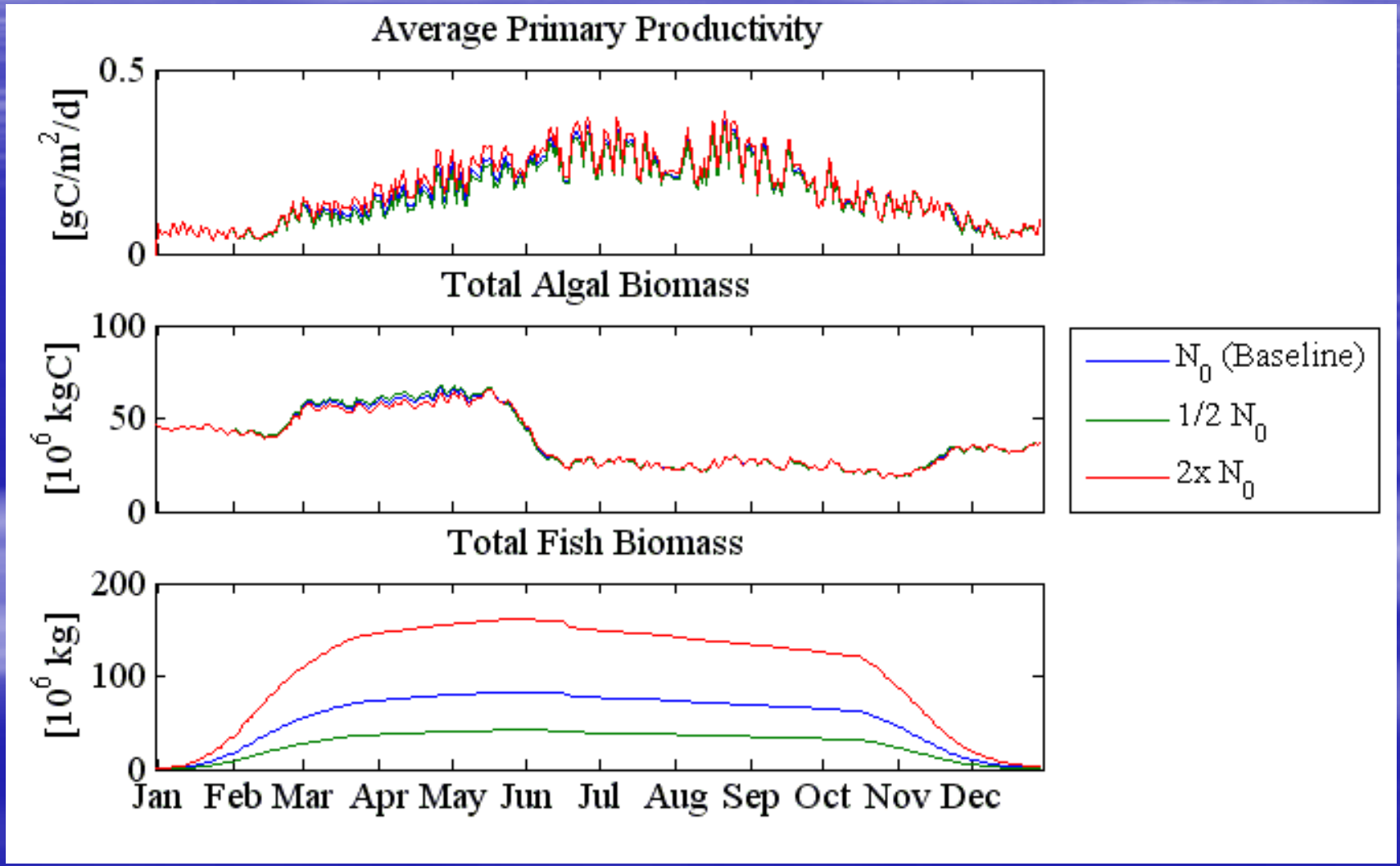
[1]2006 Stock Assessment Report for Atlantic Menhaden, 26 September 2006

Menhaden Growth

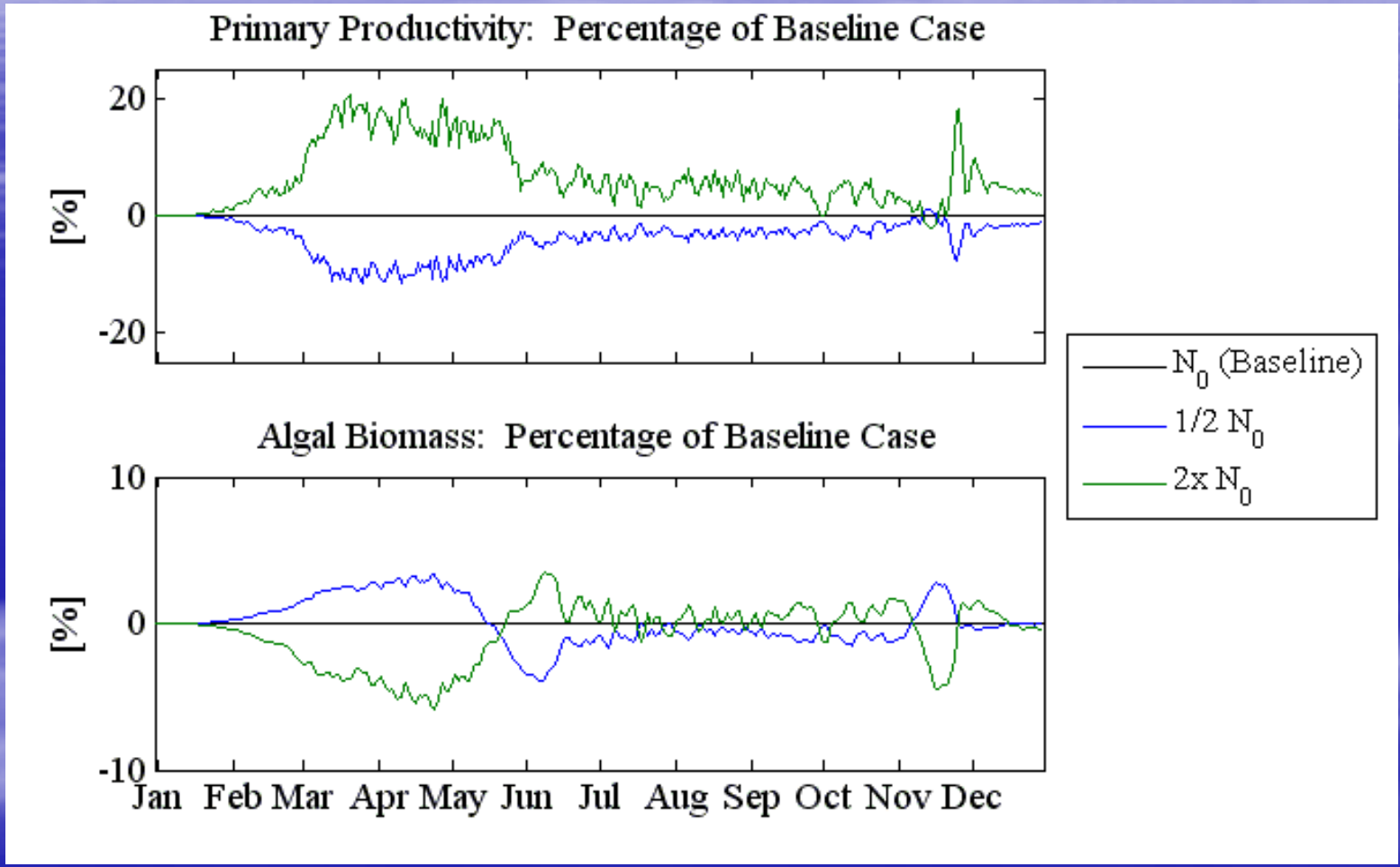


- Could be improved with: age-specific feeding fraction, improved data to calibrate entry date/weight and age-specific migration pattern

Algae Consumption

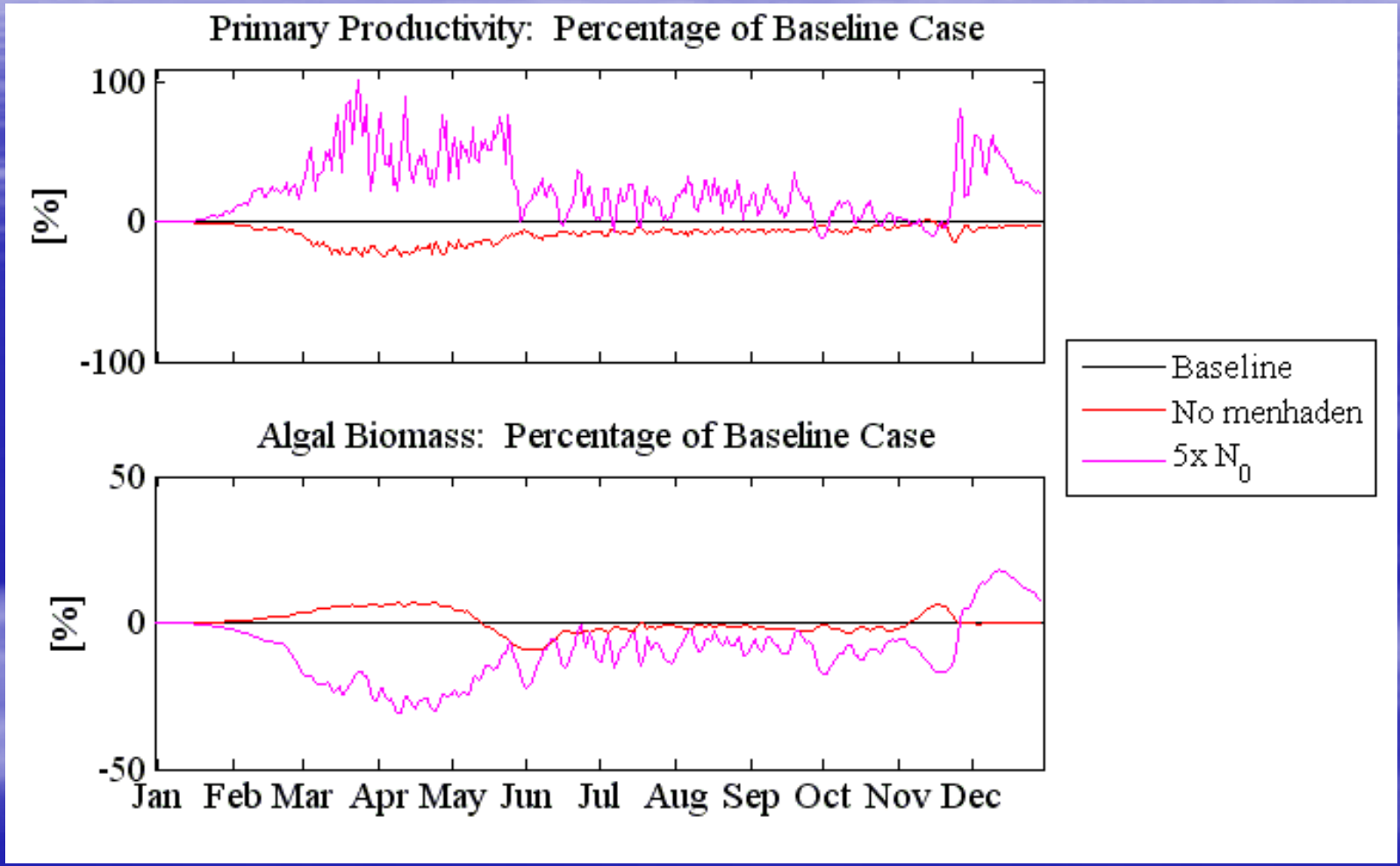


Comparison to Baseline



- Algae → local/seasonal problem
- Fish → local/seasonal consumer
- Using water quality model can capture this variability

"Extreme" Cases

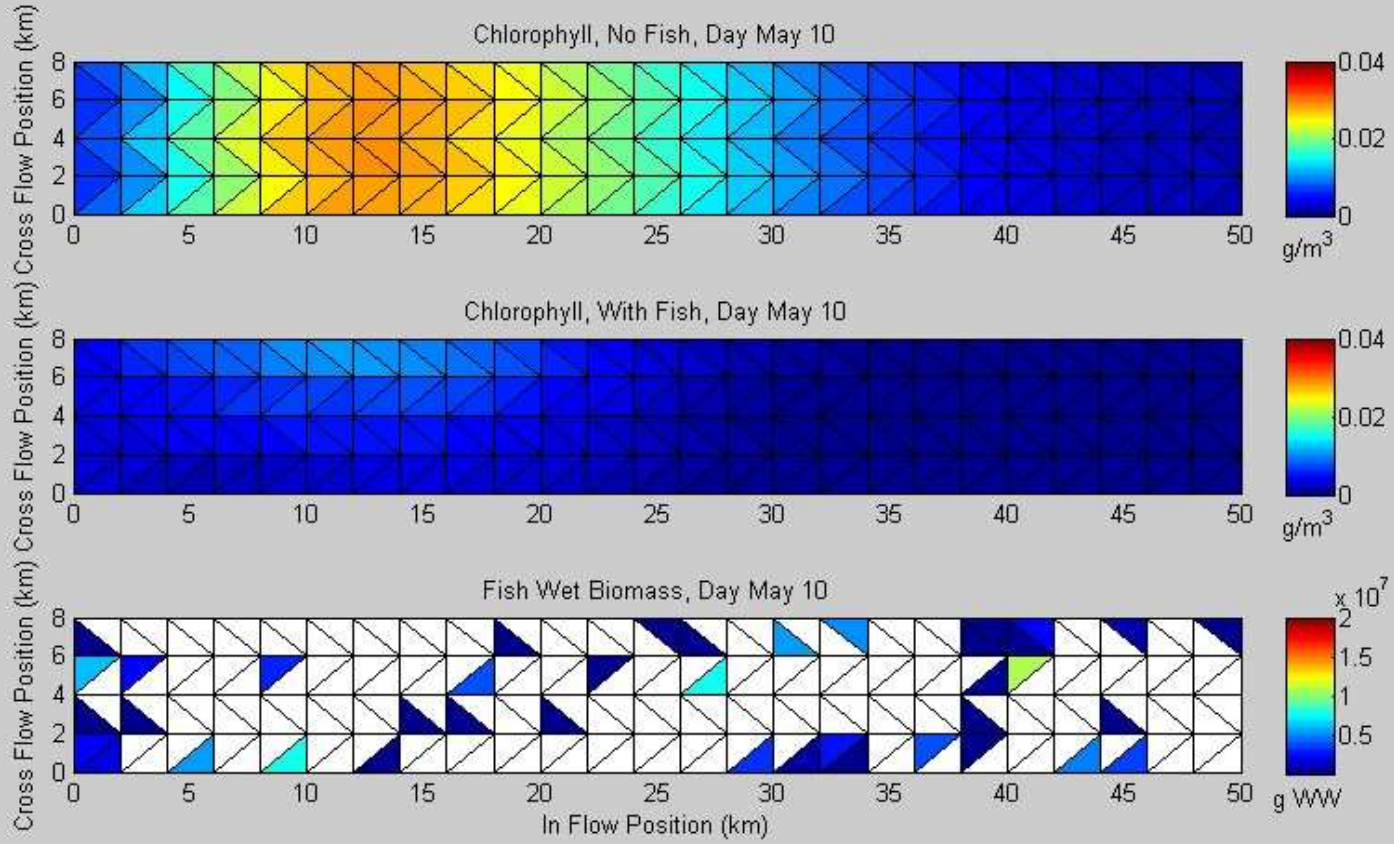


- *Primary productivity* not necessarily the problem
- Menhaden consumption keeps pace with 'excess' algal growth due to added nutrients

Key Points

- Feedback of fish to water quality (menhaden increase primary productivity, but decrease overall algae biomass)
- Fish modeled as discrete individuals (could add multiple levels of prey/predator species)
- Fish are seasonally/spatially variable consumers of seasonally/spatially variable problem (algae)…captured in model
- Fish extremely proficient at removing highly concentrated algal blooms (this effect is smoothed out in spatial/temporal averaging)

Fish vs. Concentrated Patch of Algae



Atlantic menhaden on estuarine test grid

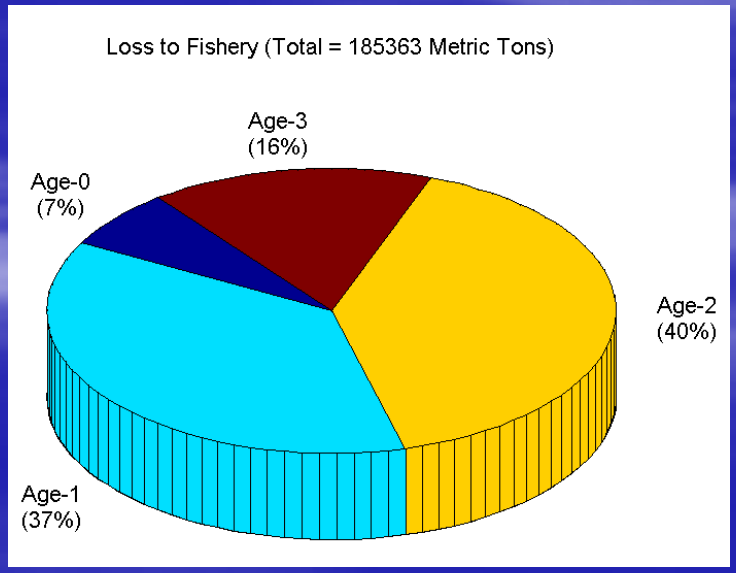
Future Directions?

- Algae as discrete particles in water quality model (replicate localized patches/blooms)
- "Smarter" fish: more accurate migration pattern, behavior responses to algae/O_2
- Tackle other fish, places, and problems:
  - Different planktivores, sites
  - Higher trophic levels (in model, or couple with population/ecosystem models)
  - Water quality effects on fish growth
  - Investigate specific management scenarios

Questions?

Fish removal: mortality, migration out

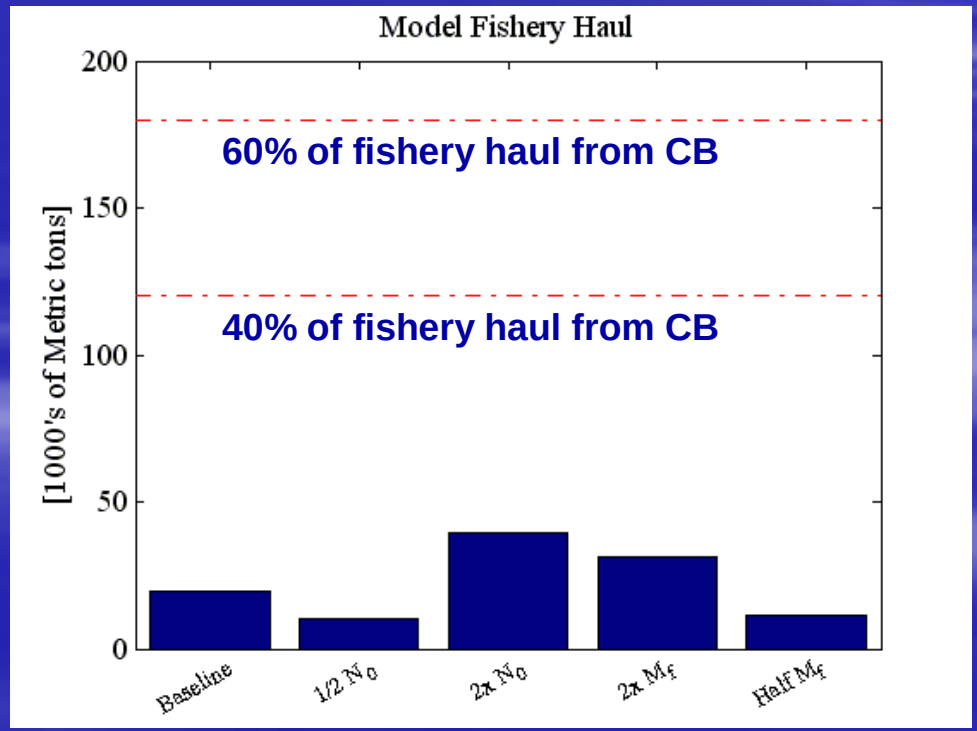
- Natural mortality (mass returns to water column): predation, starvation*, suffocation*
- Fishing mortality (mass removed from system) : Loss = fishery take → model corroboration



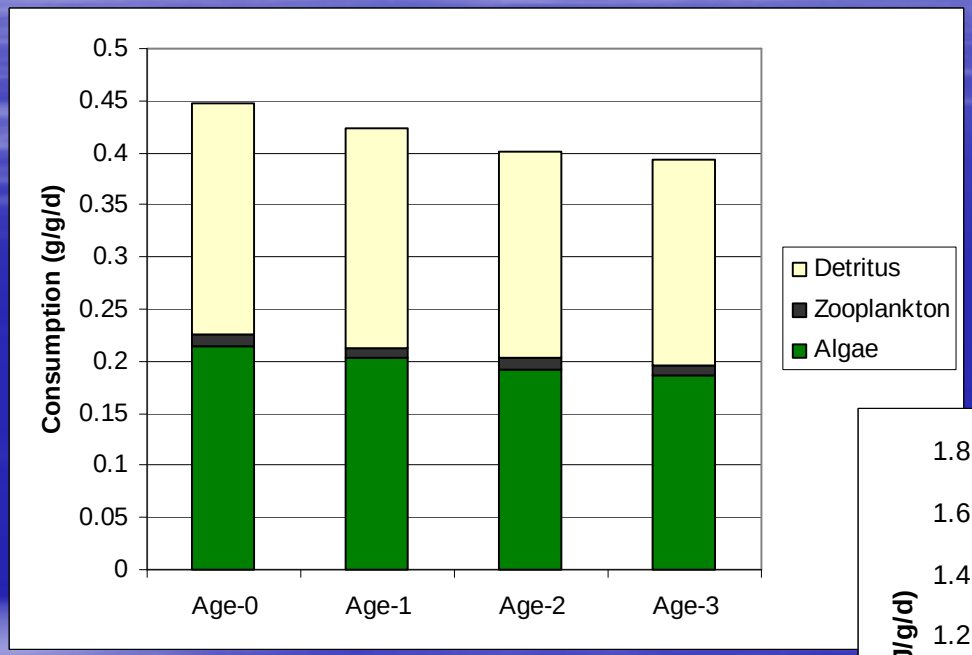
*Explicitly accounted for: result of excessive weight loss, lack of oxygen in water column

Fishing Haul

- Haul low compared to estimated catch from Chesapeake Bay
- Stock-wide fishing mortality may not be good estimate for CB
- Weight at catch may be low:
- Growth underestimated for older fish
- Fishing season vs. “catch throughout the year”

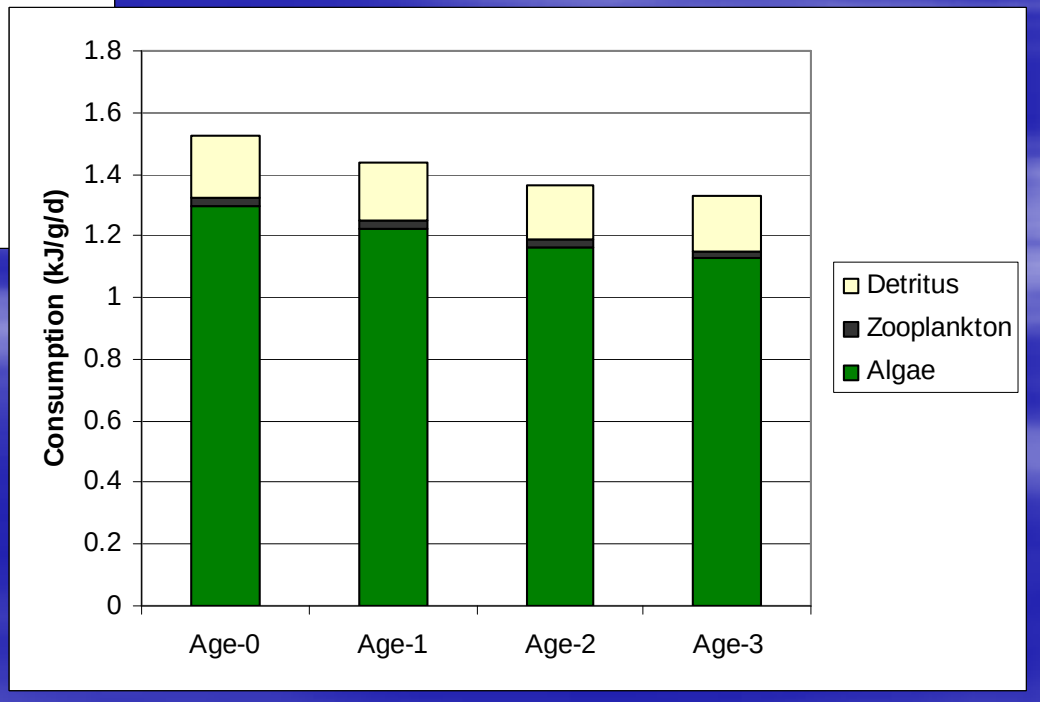


Consumption Rates



← Mass

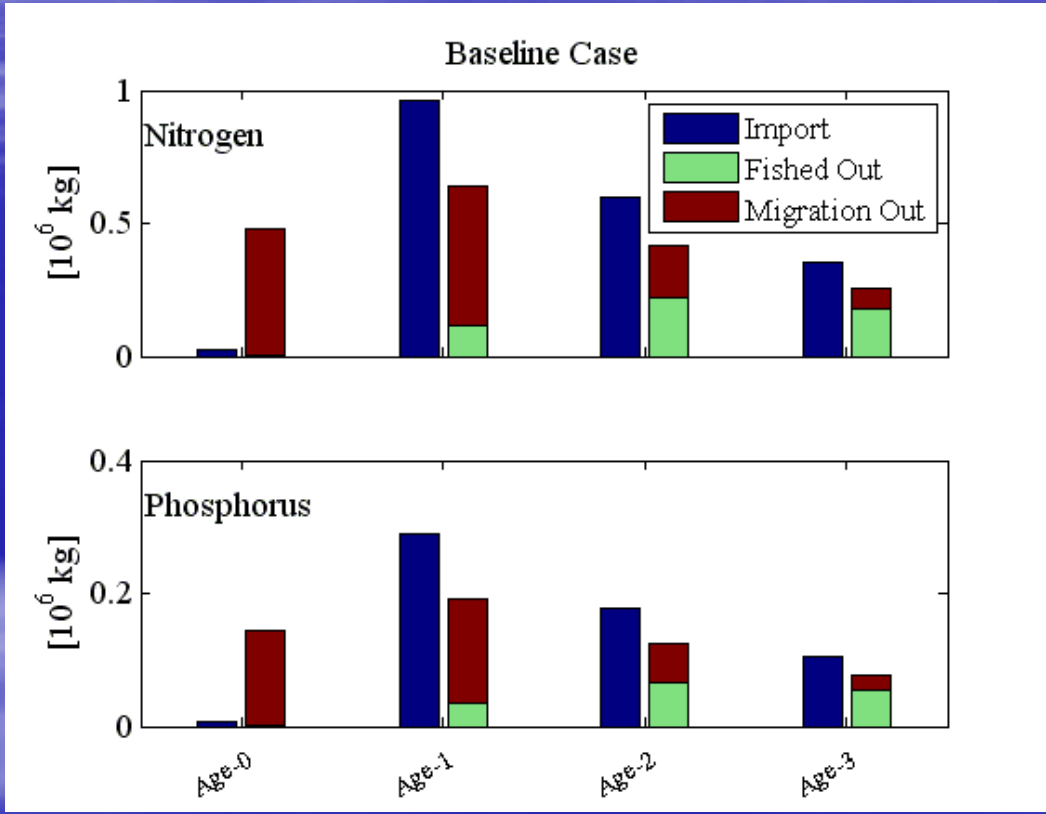
↓Energy



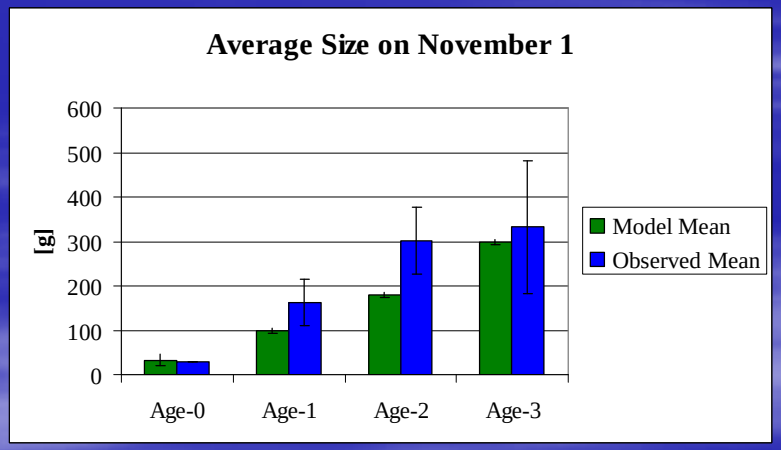
- **Within range of laboratory values of consumption**
- **No food preference in model (eat what's in front of them)**

Nutrient Export by Age Class

Age-0 fish export nutrients, older fish seem to import nutrients?



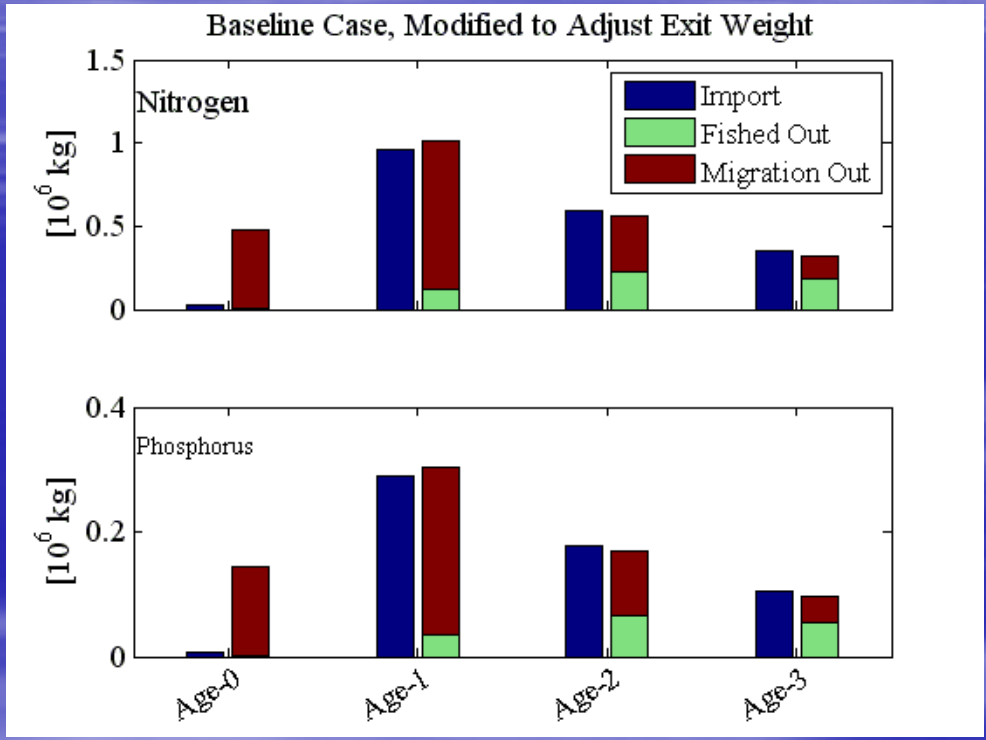
…perhaps not.



Could be result of:

- Under-prediction of growth
- Return of all natural mortality mass to the system

Nitrogen Export Adjusted for Exit Weight



- Weight upon exit modified by percent under-prediction in overall growth
- Baseline population would export 280,000 kg N
- Increased/decreased population alters net values
- Inconclusive: needs additional calibration of growth/mortality